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Integrated application of digital technologies in interconnected energy sources in renewable energy education

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ABSTRACT: This study evaluates the impact of digital technology on renewable energy education among fourth-year IT students at a Kazakhstani university through a quasi-experimental design, comparing traditional teaching methods to a curriculum integrated with digital tools, including interactive simulations. Results demonstrated that students in the digital tools-enhanced group significantly outperformed their peers in traditional settings in mastering renewable energy concepts, aligning with literature that supports the effectiveness of technology-enhanced learning. However, satisfaction levels were similar across both groups, suggesting the importance of combining traditional and digital approaches. The research highlights the necessity of blending theoretical knowledge with practical skills, noting a skills confidence gap in the digital group. This study advocates for an educational strategy that merges conventional methods with digital innovations, providing insights for educators and curriculum developers to meet the evolving demands of sustainability and technology education.

INTRODUCTION

As the third decade of the 21st century unfolds, humanity stands at the confluence of two pivotal shifts: an era of unprecedented technological innovation and a growing environmental imperative underscored by climate change and the quest for sustainable energy practices [1][2]. The convergence of these shifts highlights a critical demand for advancements that can harmonise technological growth with environmental stewardship [3][4].

In this context, the role of education, particularly in fields that bridge technology and sustainability, becomes paramount. *Integrated Application of Digital Technologies in Interconnected Energy Sources* is an educational initiative conceived at a Kazakhstani university to address this need. This course, tailored specifically for fourth-year IT students, integrates unconventional energy sources with digital technologies in an interactive, simulation-based format. Students are immersed in a practical learning environment where they can engage with and analyse the integration of renewable energy sources in IT, focusing on computer systems and data management.

An integral component of the course is a Web-based interactive simulation tool, developed with HTML and JavaScript. This tool is designed to enable students to simulate various renewable energy systems, like solar, wind and biomass, potentially enhancing their hands-on interaction with these technologies. The simulations aim to provide visual representations of energy processes, which are expected to promote active learning and may help in fostering student engagement and understanding of the complex material.

Acknowledging the innovative aspects of the course and its potential challenges, the core investigation of this study revolved around a pivotal research question: *How does the integration of digital technologies with renewable energy education impact the learning outcomes and subject mastery of fourth-year IT students?* To address this question, a robust quantitative analysis was employed, focusing on the educational outcomes as evidenced by pre- and post-test assessments. These tests were designed to quantitatively measure the knowledge acquisition and skill development before and after the course, providing a clear metric of the course's impact on students' mastery of the subject matter.

The pre- and post-test model enabled an objective comparison of students' performance, serving as a strong indicator of the course's effectiveness. By applying this quantitative method, the study aimed to yield concrete data on the educational advancement provided by the course, offering insight into the quantitative benefits of such an interdisciplinary approach to learning.

Emerging technologies, such as smart grids, energy-efficient data centres, and Internet of IoT-enabled renewable energy systems are indicative of the promising pathways that lie ahead for achieving sustainability [5-8]. The educational model is designed with an emphasis on quantitative analysis, utilising pre- and post-course assessments to examine the effectiveness of an adaptive curriculum that responds to technological advancements.

This article examines the educational benefits and outcomes of the course, using a quantitative approach to provide a detailed analysis of student learning outcomes. Conducted across two educational institutions - *Abylkas Saginov* Karaganda State Technical University (KSTU) and International IT University (IITU), both in Kazakhstan, the study engaged a sizable group of students to offer a robust evaluation of the course's efficacy. It sought to demonstrate the effectiveness of integrating digital technologies in renewable energy education and its significance in fostering a substantive contribution to the broader societal embrace of renewable energy solutions.

Through this quantitative exploration, the study endeavoured to present insights that could shape educational strategies and influence renewable energy policies, all the while contributing to the essential dialogue on how education must transform in an increasingly digitised and eco-conscious world.

LITERATURE REVIEW

The purpose of this literature review is not merely to offer a chronological or thematic representation of existing studies, but to critically identify a lacuna in current research. As one traverses this scholarly landscape, one examines the seminal works and contemporary trends that have shaped technology-enhanced learning, renewable energy education and IT integration. The authors do this to highlight a salient research gap that this article aims to address: the interdisciplinary nexus between these three domains.

Educational technology has undergone a profound transformation since the days of instructional radio and television [9]. Emerging from the theoretical frameworks of constructivism [10], technology-enhanced learning took a concrete shape in interactive simulations [11][12] and gamified environments [13].

A significant shift has been observed in student engagement and intrinsic motivation when digital tools are incorporated into the learning environment [14][15]. The efficacy of technology-enhanced learning is further substantiated by advances in adaptive testing [16] and feedback systems [17]. Bryan and Wang stated that a meta-analysis revealed a preference for traditional over technology-based education, but when properly integrated, technology can enhance outcomes [18].

Furthermore, Bryan and Wang [18] and Zhang [19] elaborated on the pivotal role that education plays in sustainable development. Innovations in pedagogical approaches include role-playing exercises [20-22] and flipped classroom models [23][24]. Researchers draw attention to the latest advancements, such as the usage of virtual reality (VR) [25], and augmented reality (AR) [26], for teaching renewable energy concepts.

The intersection of renewable energy and IT has engendered studies focused on the role of Internet of Things (IoT) applications [27][28]. Palahalli et al issued a cautionary note on the cybersecurity implications in renewable energy systems [29]. Regulatory frameworks affecting this integration are also under scrutiny [30].

The nascent yet growing literature on integrated curricula suggests that interdisciplinary approaches can be exceptionally effective [31]. Team-based learning paradigms further underscore the success of interdisciplinary educational settings [32]. While rich literature exists in each of the individual domains - technology-enhanced learning, renewable energy education and IT integration - there is a palpable gap when it comes to their intersection. Existing research predominantly narrows its focus either on the technological innovations or pedagogical aspects. Few venture into the interdisciplinary crossroads that this study aims to explore. Thus, this article seeks to fill this research void, offering a nuanced perspective on the intricate synergy between technology-enhanced learning, renewable energy education and IT integration.

By addressing these interdependent components, this study offers a critical addition to the scholarly discourse, propelling the academic community towards more comprehensive, holistic approaches to tackling the complex challenges of the modern age.

METHODOLOGY

This study employs a quasi-experimental design to investigate the impact of integrating digital technologies with renewable energy education on the learning outcomes and subject mastery of fourth-year IT students. This design was chosen for its ability to demonstrate causal relationships in educational settings where randomised controlled trials are impractical. The study involves two groups of students: a control group receiving traditional instruction and an experimental group engaging with the enhanced digital-technology-integrated curriculum.

The study involved 120 fourth-year IT students from *Abylkas Saginov* Karaganda State Technical University (KSTU) and International IT University (IITU), both in Kazakhstan. These participants were systematically divided into control and experimental groups, with careful attention to ensure a balanced representation from different majors across both universities. The division was solely based on academic year and major, without any other inclusion or exclusion criteria. The demographic distribution, including age and gender, of the participants is documented in Table 1. This balanced division was intended to ensure that any observed differences in learning outcomes could be more confidently attributed to the educational intervention rather than variances in academic background or institution.

Table 1: The breakdown of students by major and group.

Group	KSTU - Computer Technology and Software	KSTU - Information Systems	IITU - Computer Science and Org. of Digitalisation	IITU - Information Systems	Total
Control	19 students (16 male, 3 female)	14 students (10 male, 4 female)	15 students (13 male, 2 female)	12 students (9 male, 3 female)	60 students
Experimental	19 students (17 male, 2 female)	14 students (9 male, 5 female)	16 students (13 male, 3 female)	11 students (8 male, 3 female)	60 students
Total	38 students	28 students	31 students	23 students	120 students

The course titled *Integrated Application of Digital Technologies in Interconnected Energy Sources* was delivered over a single semester. The control group engaged with the standard curriculum, whereas the experimental group had the added component of a Web-based interactive simulation tool integrated into their curriculum. To assess the baseline knowledge and attitudes of the students towards renewable energy and IT, pre-course questionnaires were administered at the beginning of the semester. These questionnaires included sections on demographic information, prior knowledge, previous coursework, interest in the course and expectations. The structure of the pre-course questionnaire is detailed in Table 2.

Table 2: Pre-course questionnaire.

Section	Question	Answer type
Demography	Please provide your age, gender and major.	Multiple choice
Prior knowledge	Rate your level of familiarity with renewable energy technologies (e.g, solar, wind, hydro, biomass).	Scale 1-5
Prior courses	Have you taken any courses related to renewable energy in the past?	Yes/No
Interest in course	Rate your level of interest in the integration of digital technologies with renewable energy education.	Scale 1-7
Practical expectations	Do you expect this course to offer practical, hands-on experience with renewable energy technologies and IT tools?	Yes/No
Course expectations	How do you believe this course will impact your understanding and mastery of renewable energy concepts in IT?	Open-ended response

At the end of the semester, to evaluate the students' knowledge gain and their satisfaction with the course, post-course questionnaires were distributed. These questionnaires focused on students' mastery of concepts, the impact of digital technologies on their learning experience, practical application of the learned skills, confidence in their skills, achievement of expectations and their willingness to recommend the course. The layout of the post-course questionnaire is shown in Table 3.

Table 3: Post-course questionnaire.

Section	Question	Answer type
Mastery of concepts	Rate your understanding of renewable energy concepts after completing the course.	Scale 1-5
Impact of digital technologies	Rate how much the digital technologies used in the course enhance your learning experience.	Scale 1-5
Achievement of expectations	To what extent did the course meet your expectations in improving your knowledge and skills?	Scale 1-5
Practical application	Did the course provide practical applications of renewable energy technologies that you can apply in real-world scenarios?	Yes/No
Confidence in skills	Do you feel more confident in your skills related to renewable energy and IT after completing the course?	Yes/No
Recommendation	Would you recommend this course to other students interested in the intersection of IT and renewable energy?	Yes/No

Data from pre- and post-tests were analysed with SPSS, using descriptive statistics, paired *t*-tests, and ANOVA to compare the control and experimental groups, with a significance level set at $p < 0.05$. The study's limitations include its quasi-experimental design, potential response bias from self-reported data, and limited generalisability from the two university contexts. Validity and reliability were addressed by using established scales, pilot testing and reliability assessments through Cronbach's *alpha* and test-retest methods.

This project introduces a tool designed for automated calculations in renewable energy systems, with a focus on enhancing efficiency and data visualisation across various platforms. Unity (game engine) is utilised for its interactive capabilities, while Blender 3D and Gemini.Google assist in modelling and scripting. The user interface, designed via FIGMA, emphasises ease of use for users of diverse technical abilities. The interface's design is intuitive for inputting data and displaying results, and the tool has been thoroughly tested for functionality across different devices. Now available on-line, it aims to be widely accessible and user friendly. Illustrative figures are included to demonstrate the tool's use in educational contexts. Figure 1 shows the battery capacity interface and the biogas generator parameter interface with visuals like livestock. These figures enrich the understanding of the tool's practical applications for students.

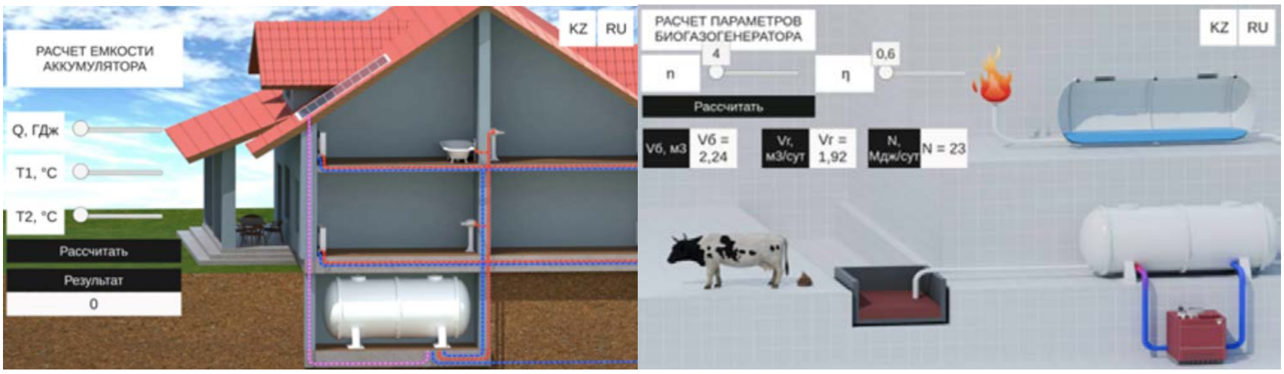

Figure 1: The user interface for calculating the capacity of a battery storage system and the biogas generator parameters.

RESULTS

Figure 2 presents a visual representation of the responses to questions in the pre-course questionnaire. The top left bar graph shows the distribution of students' self-assessed familiarity with renewable energy technologies on a scale of 1-5. It reveals a moderate level of familiarity among the majority, with the highest number of students rating themselves at 3. The top right pie chart illustrates the proportion of students who have previously taken courses specifically related to renewable energy.

A smaller portion of students have prior exposure, while the majority do not, indicating the course may be many students' initial formal education in renewable energy. The bottom left bar graph displays the levels of student interest in integrating digital technologies with renewable energy education on a scale of 1-7. Interest levels are varied, with a significant number of students expressing moderate to high interest. The bottom right pie chart shows the students' expectations regarding practical, hands-on experience in the course. A majority of the students expect the course to offer practical experiences, highlighting the importance of incorporating experiential learning components in the course design.

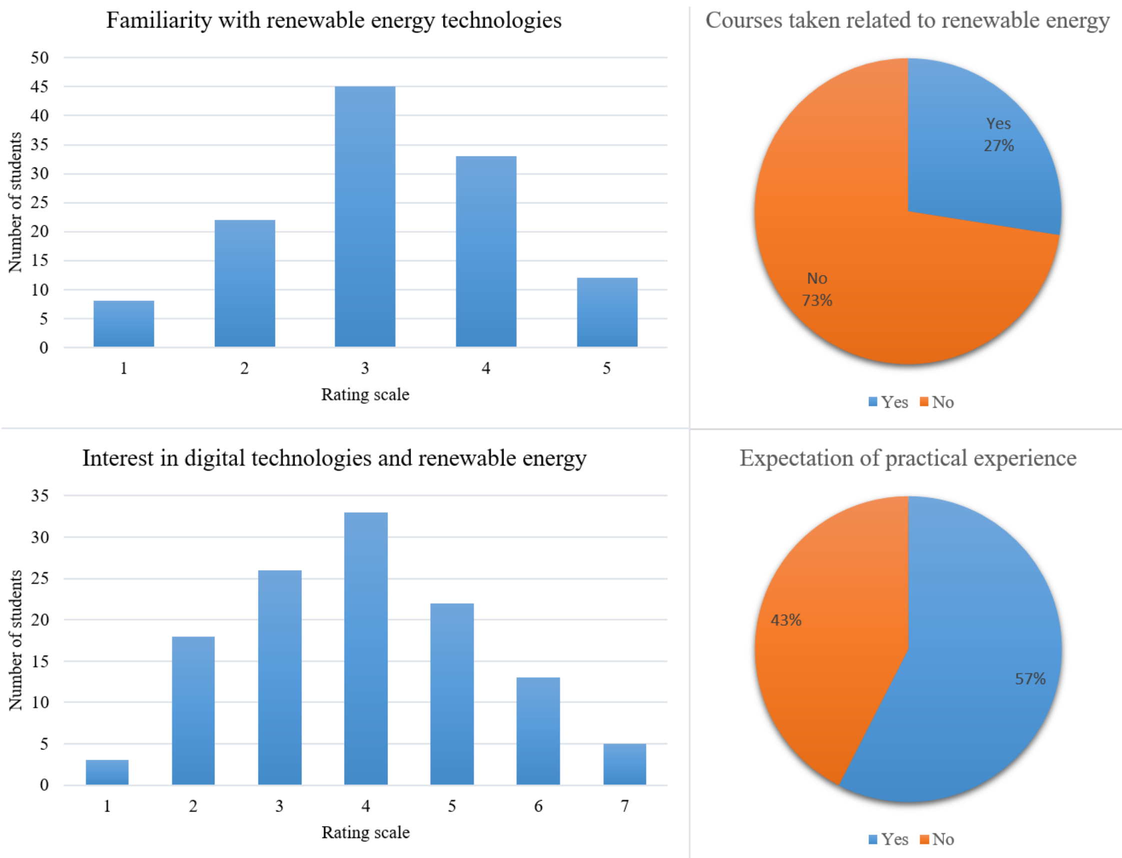

Figure 2: Pre-course questionnaire responses.

The word cloud shown in Figure 3, generated from the student responses to the open-ended question, visually encapsulates the diverse expectations and educational aspirations of students enrolled in the course. In this cloud, the prominence of certain terms like *practical skills*, *renewable energy*, *IT sector* and *sustainable development* is immediately noticeable, indicating these as primary areas of interest and focus among the students.

Figure 3: Word cloud for open-ended questions.

The varying sizes of words within the cloud reflect the frequency and emphasis of these concepts in the responses, with larger words signifying greater importance or more common expectation among the student cohort. This range of terms within the word cloud suggests that students anticipate a comprehensive and interdisciplinary learning experience. They seem to expect not only technical knowledge, but also a deep understanding of the practical applications and broader societal implications of renewable energy in the field of IT.

The presence of specific technical terms, such as *cybersecurity*, *smart grid technologies*, and *machine learning* alongside broader concepts like *climate change mitigation* and *environmental ethics* indicates an awareness among students of the complex and multifaceted nature of renewable energy systems. It underscores an eagerness to engage with both the technological and ethical dimensions of sustainable energy development.

Furthermore, the emphasis on terms related to career development, such as *career advancement* and *job market readiness* reflects an orientation towards practical and professional outcomes. It suggests that students view this course as not only an academic endeavour, but as a critical stepping stone towards their future careers in the renewable energy and IT sectors. This word cloud, therefore, provides a valuable snapshot of students' expectations, highlighting a keen interest in the practical, theoretical and policy aspects of renewable energy, and illustrates the potential of the course to impact their understanding and professional trajectory in these rapidly evolving fields.

Figure 4 presents the responses of both the control and experimental groups to the first question in the post-course questionnaire, illustrating notable differences in the students' self-perceived mastery of renewable energy concepts. This visual representation clearly delineates the varying levels of understanding between the two groups, highlighting the impact of the course structure and teaching methods on student learning outcomes. The analysis of control group shows that the mean mastery score is 3.3, with a median of 3.0 and the mode at 3, indicating a moderate level of understanding among these students.

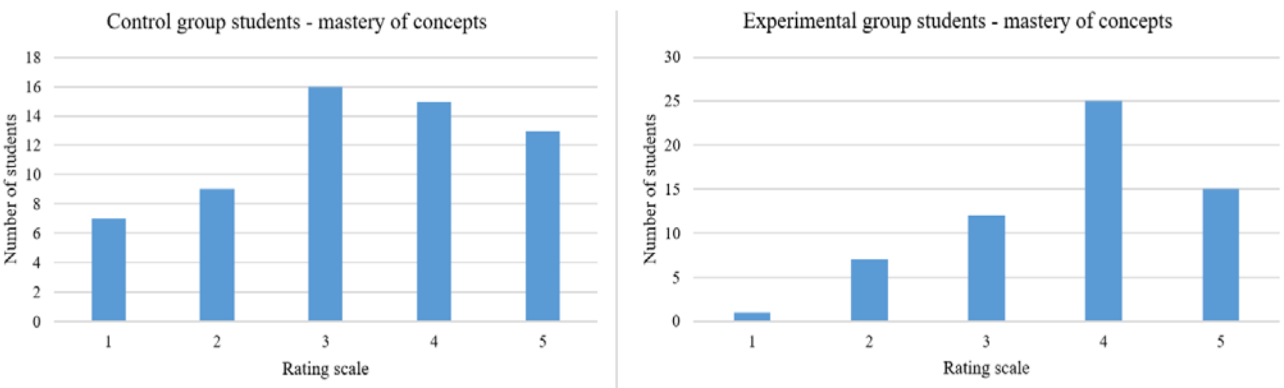

Figure 4: Responses to post-course questionnaire, question 1: control vs. experimental groups.

The distribution of responses is relatively even across the scale, peaking at 3. This suggests that while students in the control group had a good grasp of the concepts, their confidence in mastery was not exceptionally high. In contrast, the mean score for the experimental group is higher at 3.8, with a median of 4.0 and the mode also at 4. This reflects a stronger level of understanding and confidence in renewable energy concepts.

The distribution shows a concentration of responses at the higher end of the scale, particularly at 4, indicating that a significant number of students in this group felt they had mastered the material well. These results suggest that the experimental group, possibly exposed to more interactive or advanced teaching methods, achieved a higher level of mastery compared to the control group. This difference underscores the potential benefits of innovative educational strategies in enhancing student learning outcomes.

The bar graphs (see Figure 5) depicting the perceptions of the control and experimental groups towards the impact of digital technologies on their learning, with the y-axis scaled to a maximum of 25 students, present a clear comparative visual. In the control group, the distribution of ratings is broad, peaking at a rating of 4. This indicates a generally favourable view of digital technologies, suggesting that students found these tools to be somewhat beneficial in enhancing their learning experience, though not overwhelmingly so. On the other hand, the experimental group's responses show a pronounced skew towards the higher end of the rating scale, especially towards 4 and 5. This pattern indicates that these students perceived a more substantial positive impact from the use of digital technologies in their learning process. The concentration of higher ratings in this group suggests that the experimental approach, likely incorporating more innovative or extensive use of digital tools, led to a more pronounced improvement in their learning experience. These insights underscore the importance of effectively integrating advanced digital technologies in educational settings, as they appear to significantly enhance learning outcomes, especially in groups exposed to more forward-thinking or comprehensive technological implementations.

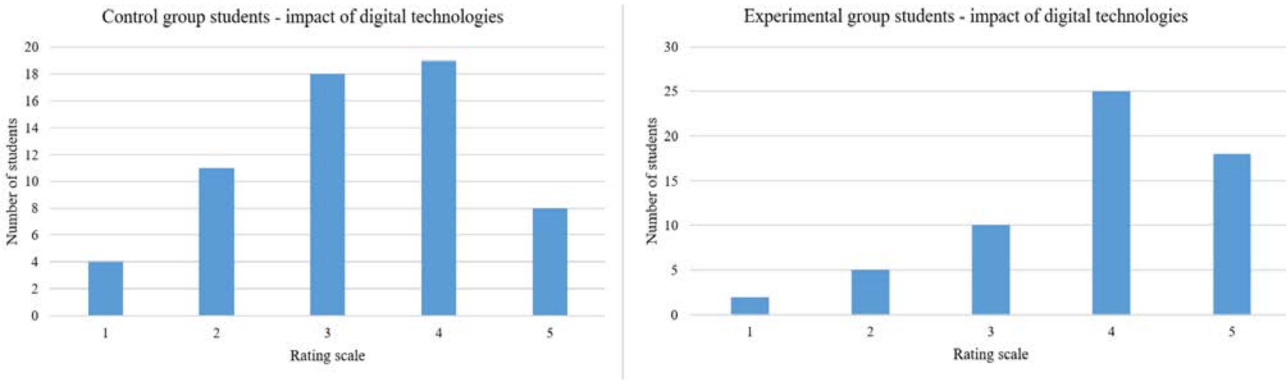

Figure 5: Responses to post-course questionnaire, question 2: control vs. experimental groups.

The bar graphs (see Figure 6) depicting the responses from the control and experimental groups to the question about the achievement of their expectations in terms of the course's impact on their knowledge and skills reveal insightful trends. In the control group, the average score for meeting expectations stands at approximately 3.6, with the median and mode both at 4, suggesting a generally positive perception of the course's effectiveness. The data indicates a skew towards the higher end of the scale, particularly at a rating of 4, implying that a majority of students believed the course adequately met or even exceeded their expectations.

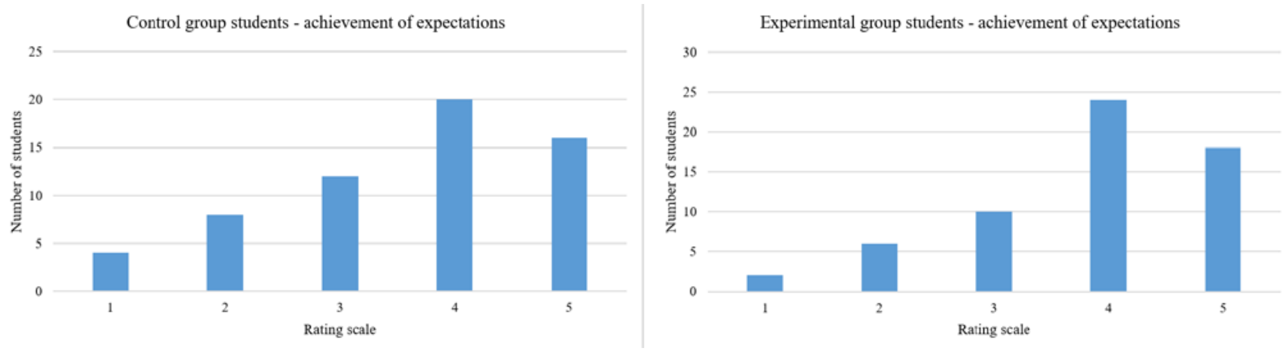

Figure 6: Responses to post-course questionnaire, question 3: control vs. experimental groups.

Conversely, the experimental group exhibits an even more favourable response, with a mean score of about 3.83 and the median and mode also at 4, demonstrating a stronger acknowledgment of the course's effectiveness in fulfilling their expectations. The distribution in this group is notably skewed towards the higher ratings, especially 4, with a significant number of students rating their satisfaction as 5. This pattern indicates that a substantial portion of the experimental group perceived the course as highly effective in enhancing their knowledge and skills. These results underscore the impact of employing innovative teaching methods and content, as seen in the experimental group, which not only met but often surpassed student expectations, thereby highlighting the value of advanced teaching strategies and course designs in boosting student learning and satisfaction.

Figure 7 (next page) presents a comparative analysis of the responses from the control and experimental groups to three critical questions concerning the course's effectiveness: practical application, confidence in skills and recommendation. This analysis is displayed in a single bar chart where each category is represented by two sets of bars, one set for each group. Within each set, the bars on the left in dark blue (*yes*)/light blue (*no*) signify responses from the experimental group, and those on the right in red (*yes*)/orange (*no*) represent the control group.

In the control group, a majority of 60% acknowledged the practical application of the course, 80% reported an increase in confidence in their skills, and about 78.7% were inclined to recommend the course to others, illustrating a general satisfaction with the course's impact.

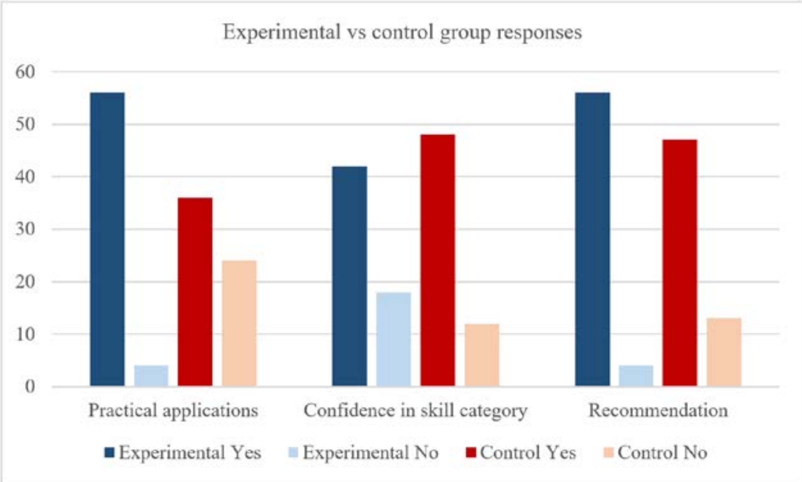

Figure 7: Responses to post-course questionnaire, question 4 to question 6: control vs. experimental groups.

Conversely, the experimental group demonstrated an even more positive response, with a significant 93.3% validating the practical application of the course and an equal percentage willing to recommend it to others, indicating a strong endorsement of the course's relevance and effectiveness. However, when it comes to confidence in skills, the percentage drops slightly to 70%, which, while still substantial, is lower than that of the control group. This disparity in responses between the two groups might hint at varying teaching approaches or differing student expectations within the course's structure, suggesting that while the experimental group highly values the practical and recommendable aspects of the course, the approach to skill enhancement might require further attention or adaptation.

The study's statistical analysis (see Table 4) indicates that integrating digital technology into renewable energy education significantly improved IT students' mastery of the subject, as evidenced by a negative *t*-value and a *p*-value below 0.05. This supports the hypothesis that digital technologies can enhance learning outcomes. Furthermore, the experimental group perceived a greater benefit from digital technology on their learning experience, with statistically significant results. However, both groups met their course expectations similarly, showing no significant difference in this aspect. Overall, ANOVA results confirm a significant impact of digital technology integration on learning in renewable energy education. The analysis underlines the benefits of digital technology in learning, although traditional and digital methods were equally effective in meeting students' course expectations.

Table 4: Statistical outcomes of digital technology integration on renewable energy learning.

Category	*t*-value	*p*-value	*f*-value	ANOVA *p*-value
Mastery of concepts	-2.1997	0.02978	-	-
Impact of digital technologies	-2.9189	0.00421	-	-
Achievement of expectations	-1.1161	0.26667	-	-
ANOVA (all categories)	-	-	12.825114	0.000389

DISCUSSION

This study, focused on the integration of digital technologies in renewable energy education for fourth-year IT students, demonstrates a significant enhancement in students' mastery of renewable energy concepts through this approach. It was found that students engaged with digital technologies displayed a deeper understanding of these concepts, aligning with the broader research trend advocating for interactive and technology-enhanced learning environments [11][12]. Simultaneously, the results revealed that both the experimental and control groups reported similar levels of satisfaction in meeting course expectations. This interesting find suggests that while digital technologies are beneficial for learning, the core content and traditional pedagogical methods maintain their efficacy and continue to be crucial in educational settings [14][15].

The study also sheds light on the balance between theoretical knowledge and practical skills in technology-enhanced learning environments. Although the course's practical focus was well-received, especially in the experimental group, there was a noted discrepancy in skill confidence between the experimental and control groups. This points to a potential imbalance where the emphasis on digital tools might overshadow the development of practical skills. Such insights are vital for educators and policymakers, highlighting the need for curricula that not only integrate technology, but also ensure comprehensive skill development and practical application. This balanced approach is essential in preparing students for the demands of an increasingly digital and environmentally conscious world.

While the study offers valuable insights, its quasi-experimental design and focus on a specific student demographic limit its generalisability. Future research could broaden its scope, including diverse demographics, longitudinal studies, and qualitative research methods to provide richer data. Investigating the effects of various digital technologies could also offer more nuanced guidance for curriculum development. Conclusively, this study significantly contributes to the literature on digital technology integration in education. It not only underscores the effectiveness of such integration in enhancing learning outcomes in areas crucial to global sustainability, but also calls for a nuanced, balanced approach in educational strategies, harmoniously blending traditional and innovative teaching methods for optimal student learning and skill development.

CONCLUSIONS

This research examined the impact of integrating digital technologies in renewable energy education for fourth-year IT students, revealing that such integration significantly enhances their understanding of renewable energy concepts. The findings endorse the use of technology-enhanced learning environments as effective in deepening students' comprehension, while also highlighting the continued importance of traditional teaching methods.

The study's results indicate a need for educational strategies that balance theoretical knowledge with practical skills, underscoring the importance of a holistic approach in modern education. Despite its focus on a specific student demographic and a quasi-experimental design, the study opens avenues for further research to broaden its scope and generalise the findings.

In summary, this research contributes to the evolving field of digital technology integration in education, especially in areas critical to sustainability. It emphasises the necessity for educational models that skilfully combine traditional and digital methodologies, preparing students for the challenges and opportunities in the rapidly evolving fields of renewable energy and IT.

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